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A remote irrigation monitoring and control system (RIMCS) for continuous move systems. Part B: field testing and results

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Abstract Precision irrigation systems can have inherent errors that affect the accuracy of variable water application rates controllers, as well as affect the controllers' performance when evaluated on different continuous move irrigation systems configurations. The objective of this study was to assess the performance of a remote irrigation monitoring and control system (RIMCS) installed on two separate linear move (LM) irrigation systems. The RIMCS varies water application rates by pulsing nozzles controlled by solenoids connected via relays to a single board computer (SBC) with wireless Ethernet connection to a remote server. The system also monitors irrigation system flow, pressure, position and wireless field sensor networks. The system was installed on a LM irrigation system in Prosser, Washington, USA and on a LM in the Nesson Valley of North Dakota, USA. For the LM at Prosser, four pre-defined irrigation patterns were imposed and variable rates were applied as a percentage of the nozzle base application rate. Each nozzle was pulsed across the span length and along the LM travel direction. For the LM at the Nesson Valley, a quadratic pattern was imposed pulsing banks of nozzles along the LM travel direction. Standard catch can tests were performed and the system performance was evaluated by comparing measured catch can water depths with pre-determined target values. The RIMCS accuracy was found to be in the range of the LM uniform water depth application uniformity coefficients of 88–96%. The RIMCS was successfully transferred to another LM in North Dakota as indicated by the relatively low variable rate application errors of –8.8 ± 8.1% and −0.14 ± 6.7% for the two spans.

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Introduction

For continuous move irrigation systems [linear moves (LM) and center pivots (CP)], variable rate water application for precision irrigation has been accomplished by varying the irrigation system ground speed, by pulsing nozzles through various mechanisms over set time cycles (Evans et al. 1996), or by varying the on-off time of one or more nozzles in a multiple-nozzle system (Bordovsky 2000). Generally, these precision irrigation systems are designed to control banks of nozzles and apply uniform application rates within a targeted water management zone or experimental plot area. Performance of continuous move precision irrigation systems has usually been determined using standard uniformity tests using catch cans for a group of nozzles applying a uniform application rate. When performed, these tests have shown that precision irrigation systems, in general, do not affect water application uniformity.

Perry et al. (2004), using collectors, showed that sprinkler cycling rate did not affect water application uniformity. They obtained a Christiansen coefficient of uniformity (CU_c; ASABE 2007) of 89% or greater for CP and a CU_c ranging from 50% to 92% for LM. In another study, Perry et al. (2002) reported a CU_c of 89% and a Heermann and Hein coefficient of uniformity (ASABE 2007) of 88% for both a 100% and a 50% application rates, under a CP irrigation system. Larger CU_c were reported by Camp et al. (1998) for a variable-rate CP system, the CU_c ranged from 91.8% to 92.2% with data obtained using 50 cups spaced 0.30 m apart along the system radius. King and Wall (2001) also obtained high CU_c for site-specific irrigation. Their results showed that the CU_c for variable water application ranged from 97% to 92% for relative application rates of 33% to 100% respectively. In general, the mean water application depths were within 10% of target depths. On the other hand, Al-Kufaishi et al. (2005) found out that pulsing nozzles at application rates of 47–50% of base rate, and at a nominal pressure of 147 kPa resulted in CU_c values of 90–95% (i.e., higher than the uniform application CU_c results of 78–89% on a CP irrigation system). Some factors that affect the coefficient of uniformity, in the direction of travel, include the alignment tolerance angle between towers, in continuous move irrigation systems, and the nozzle pattern radius as described by Heermann and Stahl (1986). In their study, the CU_c was 97.6%, 95.9%, and 90.6% for 0.5°, 1.0°, and 2.0° alignment tolerance angles respectively.

Although uniformity tests are the standard, they provide limited performance evaluation because, in most cases, the tests were done for groups of nozzles pulsing at a constant application rate, most frequently with catch cans arranged in a single dimension along the axis of the spans. A different quantification of performance of a variable rate irrigation system is through the evaluation of yields when compared to those yields under uniform irrigation application. King et al. (2002) indicated that both total and marketable yields were significantly greater ($p \leq 0.10$) under site-specific irrigation. Gross receipts were \$165/ha greater under site-specific irrigation compared to conventional uniform irrigation. Others have used simulation models and have compared results to measured values. Fraisse et al. (1995) simulated variable water application of a LM site-specific irrigation system under various water application rates (pulsing) conditions. Field evaluations were carried out to verify simulation results. Their results included a coefficient of uniformity exceeding

90% for a pulsing frequency of 1 cycle/min and a percent setting at less than 50%. The coefficient ranged from 91.9% to 95.5% in the direction of travel, compared to 92.9% for uniform application in the same direction. They used twelve sheet metal troughs ($0.10 \times 1.52 \times 0.10$ m^3) oriented with long axis parallel to the lateral and spaced 0.76 m apart in the travel direction.

Chávez et al. (2009) described a new remote irrigation monitoring and control system (RIMCS) for continuous move irrigation systems which varies water application by activating (pulsing) individual or groups of nozzles for some portion of a 60 s irrigation duty cycle for a given location as prescribed by a water application map. Since the RIMCS allows control of individual nozzles over short time intervals, it is possible to vary water application rates in two dimensions (i.e., along the span and in the direction of travel). Continuous variable water application patterns that can be created within a field provide new opportunities for precision irrigation and their performance evaluation.

The goal of precision irrigation control systems is to apply accurate target (set) water application depths by location in the field. The objective of this study was to evaluate (1) the performance of the RIMCS precision irrigation system in terms of standard uniformity tests, (2) the accuracy relative to target water application depth patterns within a field, and (3) the RIMCS performance when installed and operated on a LM irrigation system configured differently than the Prosser LM system (RIMCS transferability).

Materials and methods

Performance of the RIMCS system was evaluated at two locations: the WSU Irrigated Agricultural Research and Extension Center near Prosser, Washington, USA (Latitude 46° 15′ 6.40″ N, Longitude 119° 44′ 21.64″ W) where the system was developed and at the North Dakota State University Experimental Farm located in the Nesson Valley, about 40 km east of Williston, North Dakota, USA (Latitude 48° 9′ 52.53″ N, Longitude 103° 6′ 9.79″ W). A full evaluation of the system was performed at the Prosser site while the Nesson Valley location served as the test site for the transferability of the RIMCS.

System evaluation at prosser, Washington

The RIMCS system was designed and developed as described in Chávez et al. (2009), on a four-span Pierce AcreMaster[1] Mini Lateral Move (Pierce Corporation, Eugene, Oregon, USA) continuous move irrigation system operating on a 2 ha field containing soils mapped as Warden sandy loam and an average longitudinal slope of approximately 5%. The 30-year average seasonal precipitation at this location is 70 mm. The LM was retrofitted with the RIMCS technology so that each nozzle in the first two spans was controlled by a single relay board located on the middle tower via a single board computer installed at the cart. Each span measured 36 m long and was retrofitted with two 18 m long PVC manifolds. Each manifold contained a 38.1 mm solenoid valve, a pressure transducer and a flow meter. From the manifold, six hoses (drops) were supplied each with one Senninger 4.76 mm i-wob nozzles (#12-red deflectors) installed in line with a 25.4 mm solenoid valve and a 65 kPa pressure regulator. Under this arrangement, nozzles were outputting

[1] Mention of trade or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture or Washington State University.

0.72 $m^3\ h^{-1}$ of water flow producing a wetted diameter of approximately 10.0 m for the installation height of 1.2 m from the ground level. The RIMCS system controlled water application rate at each nozzle via a relay board wired to each solenoid. The relay board was connected via a serial cable to a single board computer (SBC) programmed to send a control string to the relay board every minute with settings for each nozzle as to how many seconds over the next minute that nozzle should be applying water. The time setting varied by location that was determined by a GPS mounted at the first nozzle on the irrigation system.

The SBC used a map of "ON-TIME" values that was updated remotely via a wireless Ethernet bridge. The SBC also collected pressure and flow data from a sensor network installed on the LM and from another sensor network of soil water sensors in the field. It was also designed to automatically populate a remote server database via the wireless Ethernet bridge.

Four water application patterns were imposed in 30 $\times$ 36 m blocks in each of the two spans as illustrated in Fig. 1: (from south to north) a linear increasing pattern, a linear decreasing pattern, a quadratic pattern, and a uniform application. These patterns allowed us to assess water application uniformity under single rate, continuous water application and variable rate (pulsed) water application rates both along the span and in the direction of travel. Water applications were varied from 20% to 100% of the nozzle nominal water application rate (depth) for the linear increasing and decreasing irrigation patterns. The corresponding target percent application rates for catch cans between nozzles were: 20%, 27%, 34%, 42%, 49%, 56%, 64%, 71%, 78%, 85%, 93%, and 100% while the water application variation was from 30% to 100% (30%, 56%, 76%, 89%, 96%, 100%, 100%, 96%, 89%, 76%, 56%, and 30%) for the quadratic pattern. For the constant or equal application pattern, 70% of the nozzle base application rate was chosen. The base application rate (BAR) was a function of the barley water consumption

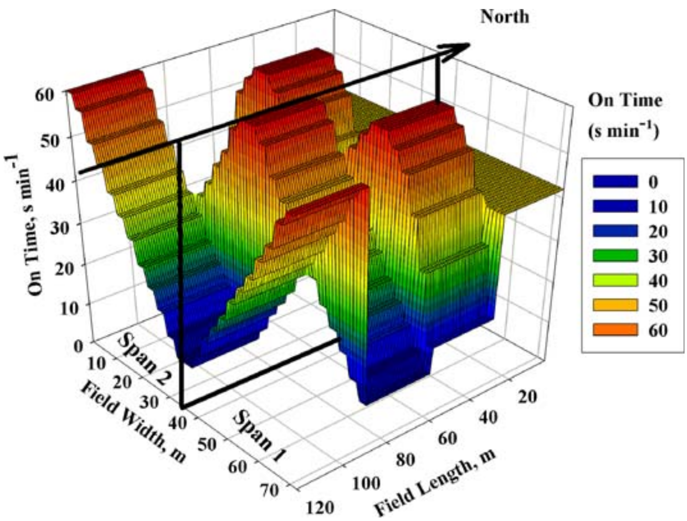

Fig. 1 Three dimensional display of the water application patterns imposed on the LM in Prosser, Washington, including linear increasing, linear decreasing, quadratic, and uniform with patterns repeated in both spans

rate (ET_c), for the month of June and, for August/September, BAR was a function of set water depths.

Catch can tests were performed following the ANSI/ASAE S436.1 standards (ASABE 2007) and the Farm Irrigation System Evaluation guide of Merriam and Keller (1978). Three different catch can tests were performed as illustrated in Fig. 2, with 19 separate tests performed during the summer of 2005 (Table 1). One test measured water application depths along each span conducted in the middle of each irrigation pattern blocks, a second test conducted along each span at the block boundaries, and a third test in which banks of nozzles were pulsed along the travel path of the LM in the quadratic pattern. For the first test, two rows of catch cans were placed between nozzles at 3 m spacing. For the second test, five rows of collectors were placed spaced 3 m between nozzles and 2 m between rows with the middle row aligned with the block boundary line. For the third test, three

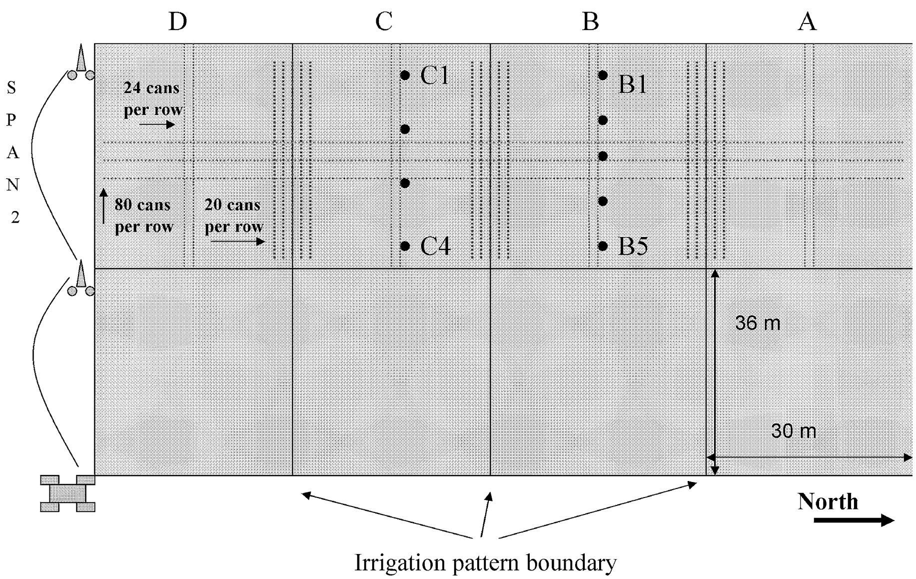

Fig. 2 Catch can tests layout for the WSU irrigation system

Table 1 List of catch can test dates during 2005

Pre-harvest	Travel direction	Post-harvest	Post-harvest	Travel direction
June 14	North	August 12	August 15	Static
June 17	South	August 15	August 18	South
June 20	North	August 16	August 19	North
June 21	South	August 22	August 25	South
June 23	North	August 23	August 26	North
June 24	South	August 30		South
		August 31		North
		September 20		East, West

North-South LM travel direction tests for the WA tests, while for the ND tests the LM traveled on the East-West direction rows of catch cans were placed between nozzles in rows perpendicular to the span with cans spaced 2 m apart along the direction of travel.

In addition, the Christiansen coefficient of uniformity (CU_c, Christiansen 1942) and the typical LM nozzles average water application rate determination tests were performed with eight rows of catch cans placed parallel to the span length arranged in a 1.5×1.5 m^2 grid.

The June tests were performed in 1.5 m wide alleyways cut into the barley crop in the middle of each irrigation pattern block with catch cans positioned as indicated by the location of the letters A, B, C, and D in Fig. 2. The August tests were performed after the August 2nd harvest.

Besides catch can tests, another measure of system performance undertaken included the evaluation of the amount of deviation that existed between the actual applied “ON-TIME” map and the target “ON-TIME” map. The difference between these maps has to do with the GPS reading accuracy. The intended (target) amount of seconds “ON” per solenoid valve position (in the field) could be different from the actual number of seconds that the valve remained “ON” at a given position due to GPS errors and due to the “ON-TIME” map cell/pixel size resolution of 1×1 m^2. In this regard, one advantage of the SBC is that it saves the actual “ON-TIME” sequence per location. This actual map was used in a comparison to the original (intended) target “ON-TIME” map.

The comparison between actual and target “ON-TIME” maps was performed in June 2005 in a Geographic Information System (GIS) environment using the Environmental Systems Research Institute, Inc. (ESRI) ArcGIS v9.0 software (Redlands, California, USA).

Evaluation of the RIMCS system in Nesson Valley, North Dakota

To evaluate the performance of RIMCS in a different LM configuration, the system was installed on spans 2 and 3 of a 7 span Valley LM system. The LM system was located in the Nesson Valley of western North Dakota and the test was carried out in September 2005. The spans were 48 m long and were sub-divided into 3 banks of nozzles, each bank with 10 nozzles controlled simultaneously by air-actuated solenoid valves. The nozzle spacing was 1.5 m and the nozzle type was Nelson S3000 Spinners, #31, D6–12° red plate, 1.45 m^3 h^{-1} at 98 kPa regulated pressure.

The nozzle wetted diameter was 12.8 m at 1.0 m height. The RIMCS control box and relay board were installed at the cart because solenoids for the nozzle banks were already wired to the cart for use in a different control system. Because the Nesson Valley system controlled banks of nozzles rather than single nozzles, as in the Washington State system, the application patterns were different as illustrated by the quadratic application pattern in Fig. 3.

A different catch can test was devised to evaluate the system performance, seven clusters of 9 catch cans were arrayed in a 0.75×0.75 m^2 grid and positioned in the middle of 12 m long blocks aligned along the travel path of the middle bank of nozzles of spans 2 and 3. Irrigation application rates were varied 20%, 60%, 88%, 100%, 88%, 60%, and 20% of base application rates per irrigation zone, along the travel path of the span.

Potential sources of catch can errors

Some of the variable water application errors may be explained by errors from external sources (other than the control system) such as sprinkle water evaporation-drift, catch can evaporation, catch can shape effect and graduated cylinder reading error.

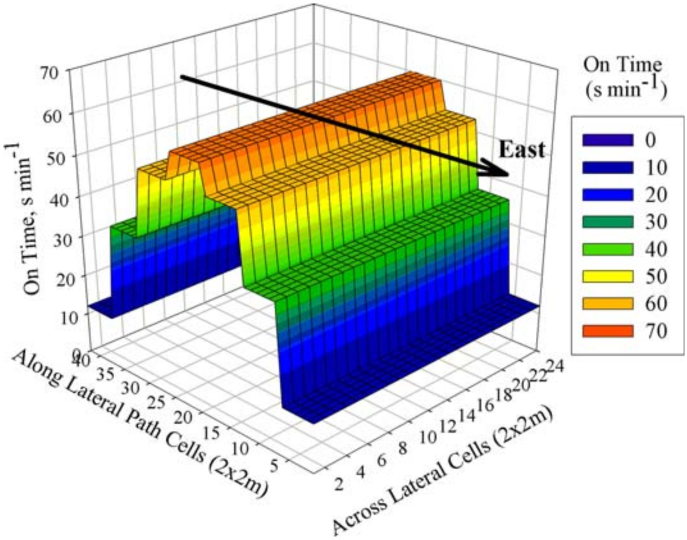

Fig. 3 Imposed quadratic water application pattern in Nesson Valley of North Dakota

Statistical analysis

The comparison of actual variable water depths applied to target application water depths for the different imposed water application patterns was carried out comparing 'mean bias error' (MBE) and 'root mean square error" (RMSE) expressed in percent. These are the mean and standard deviation errors respectively. Their definitions follow:

$$\mathrm{MBE} = \frac{1}{n}\sum_{i=1}^{n}\left[X(M)_i - X(O)_i\right] \tag{1}$$

where n is the number of pairs compared, $X(M)_i$ is the actual water depth applied value and $X(O)_i$ is the target set value. A positive MBE means that the system over-irrigated.

$$\mathrm{RMSE} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left\{\left[X(M)_i - X(O)_i\right] - \mathrm{MBE}\right\}^2} \tag{2}$$

Also, the linear least squares regression method was utilized in evaluating the irrigation control system capacity to deliver set amounts of water per location.

Results and discussion

System evaluation at Prosser, Washington

The comparison of the submitted SBC "ON-TIME" maps to the relay board controller actual executed maps resulted in an "ON-TIME" values positioning average deviation of 2.5 ± 1 m. Figure 4 depicts a GIS plan view of the "ON-TIME" map values where the valves' positioning error at the border (black lines) between irrigation patterns can be observed. This deviation is attributed to the GPS unit reading errors. The error is

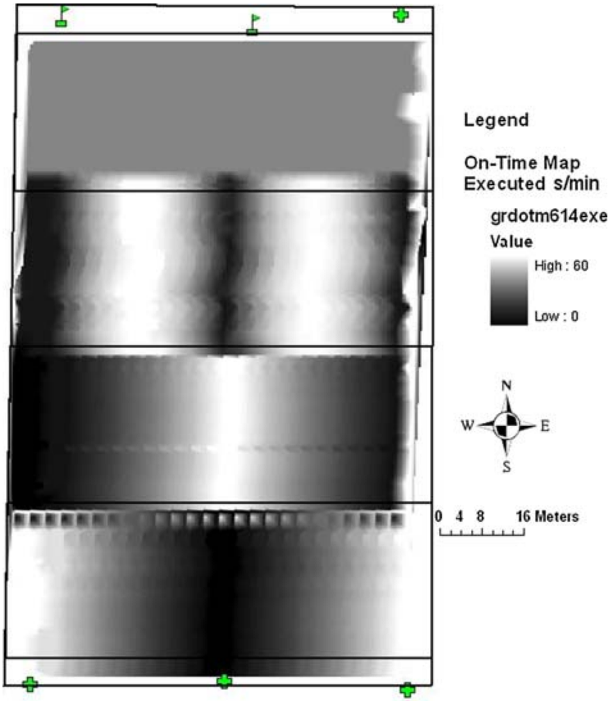

Fig. 4 GIS raster of a typical executed “On-Time” map

considered very small when compared to typical sizes of irrigation zones and when considering that at the borders between irrigation zones there will be water application depth or rate blending.

The SS100 remote soil water content radio network performed well during the irrigation events, sensing and sending the soil moisture data on a continuous basis without problems or loss of data. Data were transferred without incidents to the remote database.

In terms of catch can tests, the first step in evaluating the performance of the RIMCS was to evaluate the Prosser LM system under uniform water application rates. The CU_c determined for the uniform water application pattern was 96.5% when tests were conducted under the low wind conditions of August 15 (Table 2), a comparatively high value for this coefficient. The CU_c, as expected, declined with wind, decreasing to 88.0% when the wind speed doubled to 1.8 m s^{-1} during the August 16 test. Other contributing factors to the decrease in CU_c on August 16 test may have been the shorter irrigation duration and the fact that the LM was traveling in the downhill (South) direction with the wind direction

Table 2 A typical CU_c for the Prosser LM Nozzles’

Date	Time	PT (%)	U (m s^{-1})	θ (°)	CU_c
August 15	13:00–16:00	5	0.9	115	96.5
August 16	11:00–13:00	10	1.8	230	88.0

PT is the LM percent timer setting, U is the horizontal wind speed, and θ is the wind direction (degrees from North) coming from the South-West. The uniform water application efficiencies determined here were in line with reported values in the literature.

The catch can test with the LM spans centered in the middle of eight rows of can collectors was used to verify the theoretical calculation of the LM average application rate. The theoretical calculation utilizes the nozzle nominal flow, wetted diameter, spacing, spans length and other inputs. The verification was needed to select the proper nozzle water application rate in the computation of water depths applied during the different variable irrigation events [different percent timer (PT) settings].

This calculated target water application depth was used in the evaluation of the RIMCS irrigation system variable application patterns collected by the catch cans. The difference between the calculated or estimated water depth applied (H est.) to the actual measured depth (H meas.) for catch can tests was 1.3% on August 12 increasing to −5.5% on August 15 due to higher wind speed which decreased the nozzle water application efficiency (Table 3).

RIMCS was evaluated at the irrigation pattern block boundary as illustrated in Fig. 5; where a transition from the uniform 70% to the quadratic application rate is shown. Starting 5 m (nozzle wetted radius) perpendicularly from the boundary and in both

Table 3 WA lateral move nozzles average water application test

Date	08.12.05	08.15.05
Time (PDST)	15:15–16:15	8:00–9:00
H est. (mm)	23.8	23.8
H meas. (mm)	24.1	22.5
Difference (mm)	0.3	−1.3
Difference (%)	1.26	−5.46
U (m s^{-1})	0.6	1.4
H = water depth		

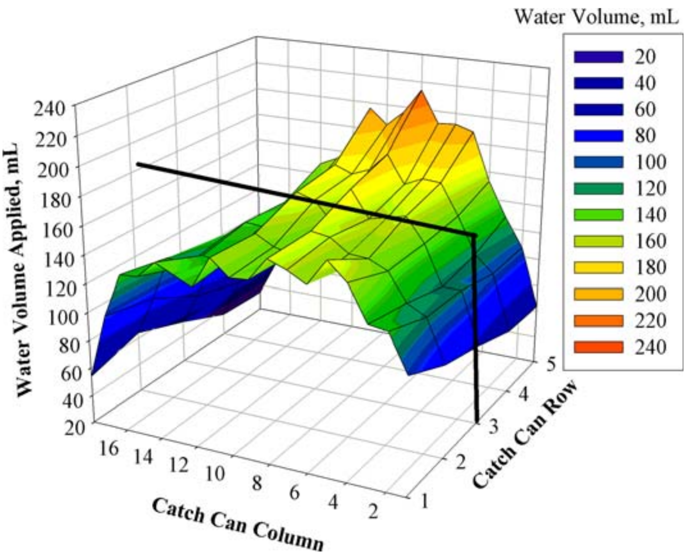

Fig. 5 Uniform to quadratic water application pattern transition at block boundary

directions, North/South, an average water depth (application blending) between consecutive variable irrigation application patterns was expected. In the evaluation, a comparison was made between the measured and the expected (target) water depths.

Table 4 presents the results for the boundary displayed in Fig. 5. In this table, rows 1 and 2 showed low MBE ± RMSE while rows 3 through 5 showed an increasing application error as the system traveled southward. Similar low errors for all rows would have indicated proper variable irrigation pattern switching at the block boundary; however only rows 1 and 2 follow this logic, which is an indication that RIMCS switched irrigation patterns 4–5 m before reaching the boundary. This 4–5 m positioning error may be attributed to the GPS accuracy, which was 2.5 ± 1 m, as the executed "On-Time" map evaluation indicated previously, and also to the towers stop/advance pattern and cart alignment related errors. Nevertheless, knowing where in the field application errors occur allows RIMCS to compensate by shifting location of irrigation zones accordingly.

As reported previously, the typical constant rate water application uniformity was high. Thus the next evaluation referred to how variable rate water application, from pulsing nozzles, affected water application efficiency both along the axis of the LM and along the direction of travel.

For two irrigation events in June 2006, water application depths along the axis of the LM followed the intended pattern but were lower than target depths when the LM was moving north (June 14, 2006) and higher than target depths when the LM was moving south (June 17, 2006; Fig. 6). When the two irrigation events were combined, the match between actual and target water application depths greatly improved with MBE and RMSE values decreasing to about −4 ± 5% for these catch can tests (Table 5). Recall that the LM was installed on a field that sloped to the south with an average slope of approximately 5%, which makes the alignment and proper movement of the LM difficult. It was observed that the LM spans stopped at different positions relative to the catch cans, introducing variability in water delivery to the catch cans from one application to another. Some error is expected in that LM machines are restricted to operating on long, smooth to gently rolling fields with slopes not more than 2–3% in the direction of travel and 1–1.5% along the lateral (Keller and Bliesner 1990). Considering that the LM did not stop at the same location on each irrigation event and that the cart movement (stop/advance) pattern mostly affected how the first two spans' nozzles delivered water, the water application error was analyzed using the cumulative water depths applied (i.e., adding irrigation water depths for the month of June and separately the ones for August (Table 5)).

In another study, the car movement pattern was modeled and the model was used to adjust the water application map in the RIMCS reducing water application errors to ±5% (Chávez and Pierce 2006). Accordingly, by combining irrigation events, the overall variable irrigation application errors decreased to a range of −2% to −8% for the MBE and to a range of 3% to 7% for the RMSE, respectively, much smaller errors than those observed in single irrigation events. Consequently, the magnitude of errors decreased with cumulative water application

Table 4 Uniform to quadratic water application rate (water depth) error at block boundary

Catch can row number	MBE (%)	RMSE (%)
Row 1 (Northern row)	−5.1	6.3
Row 2	−9.2	6.4
Row 3	−8.2	11.5
Row 4	−8.7	17.5
Row 5 (Southern row)	2.6	23.6

Table 5 Cumulative variable irrigation error assessment

June Irrigation events #	Cumulative water depth (mm)	Travel direction North/South	Span 2 variable irrigation pattern			
			Linear increasing		Linear decreasing	
			MBE (%)	RMSE (%)	MBE (%)	RMSE (%)
1	17.4	North	−10.5	8.9	18.9	5
2	21.6	South	−3.9	6.2	16.1	10.3
3	36	North	−11.8	5.1	19.3	11.7
4	55.9	South	−5.5	4.5	6.7	5.2
5	70.9	North	−5.9	3.8	7.4	5.6
6	85.9	South	−3.2	3.9	9.6	6.7
August irrigation events						
1	15.4	South	5.2	3.4	−5.8	8.2
2	30.8	North	−5.1	3.0	6.6	3.9
3	46.2	South	−0.6	4.2	−4.6	4.4
4	61.6	North	−1.8	3.3	−8.3	3.5

depth applied. Figure 6 illustrates the error decrement for the "linear increasing" water application pattern of span 2. In this figure, the top graph shows the under application of water on June 14 when the LM traveled north (uphill) while the middle graph shows the over application on June 17 when the LM traveled south (downhill). The substantial improvement in variable rate water application is shown in the lower graph of Fig. 6. This last graph shows the cumulative water depth applied (i.e., the combined water depths of the test of June 14, 17, 20, 21, 23 and 24) that better agreed with target values. In terms of percent errors, Fig. 7 plots the MBE and RMSE for the "linear increasing" water application pattern (span 2) as a function of cumulative water application depth. In this figure, the RMSE (solid circles) decreased from close to 9% for a single irrigation event to about 4% when six variable rate irrigation events were combined (cumulative water depth applied). The RMSE decrement was characterized by an "exponential decay" curve while the MBE decrement was better characterized by a linear fit. In the case of MBE (empty triangles), the first 2–3 irrigation events displayed moderate scattering; however, the subsequent fourth, fifth and sixth irrigations reduced the average variable rate water application depth error to about only −3% (slight under application error). Therefore, after six irrigation events, the water application errors were substantially reduced.

Additional tests in August (Table 5) showed small water application errors after four irrigation events. This better result may be due in part to the fact that the catch cans were installed on the ground surface and not above the barley canopy as in the earlier tests. Due to the placement height in the June tests, the cups were more susceptible to wind speed effects. According to Kincaid (2005), increasing the mounting height can reduce application rates, but this increases wind drift.

The catch can test of the quadratic application pattern along the travel direction of the LM on August 30 and 31 showed similar results that again were improved when data from the two dates were combined. The regression of actual application depth on target application depth for the combined data set had a coefficient of determination (R^2) of 0.97 although the MBE and RMSE values were −7.3 and 9.9% respectively, for an irrigation base water depth of 19.4 mm (Fig. 8). This error of about 10% is similar to the error found in the June and August tests when individual nozzles were pulsed along the span length.

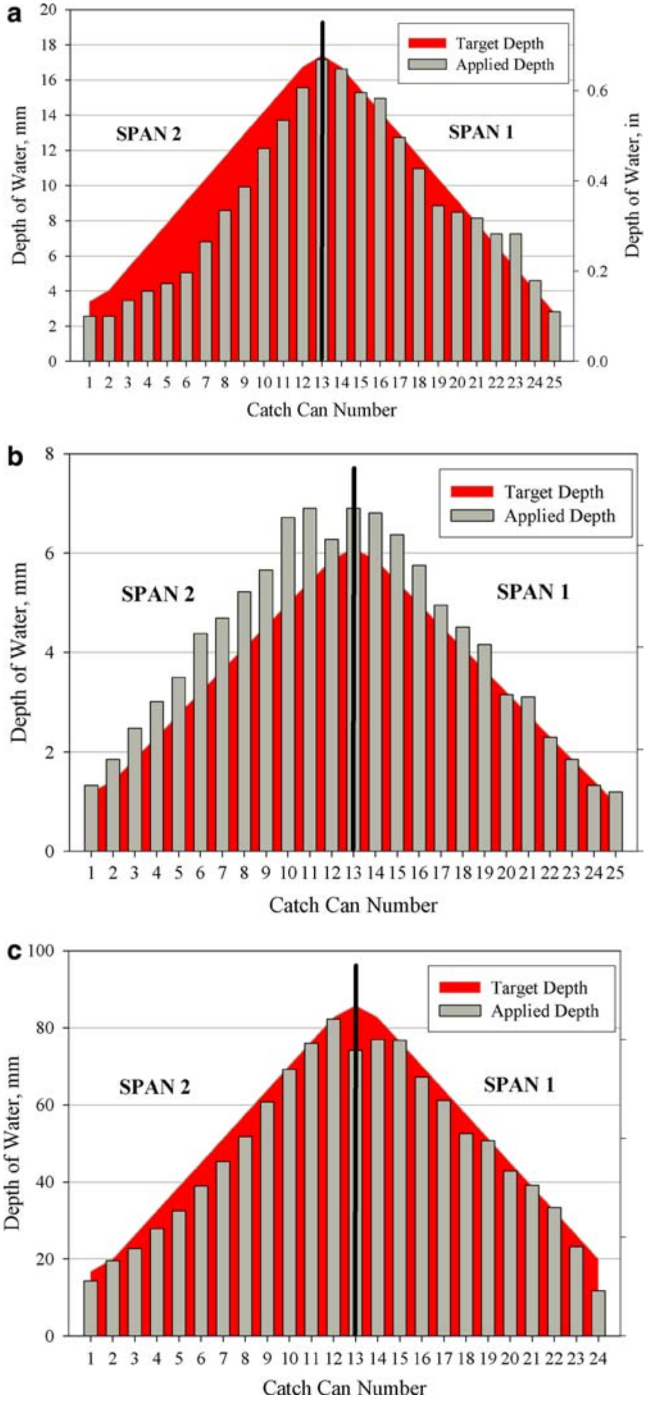

Fig. 6 Comparison of actual and target water application depths for the linear application patterns. Tests of June 14 (*top*), June 17 (*middle*), and cumulative water depth of June 14, 17, 20, 21, 23, and 24 (*lower graph*)

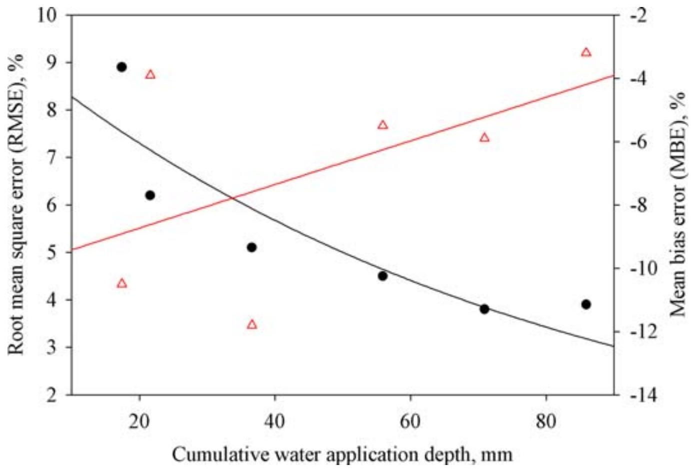

Fig. 7 Cumulative water application depth error for the linear increasing pattern of span 2

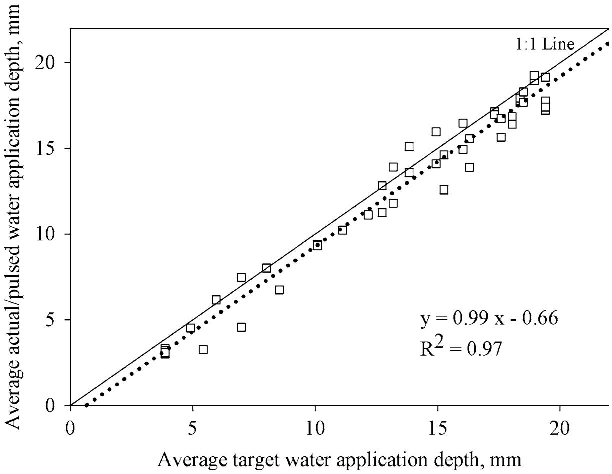

Fig. 8 Comparison of the cumulative quadratic application, target versus applied, August '05

Evaluation of the RIMCS in Nesson Valley, North Dakota

The RICMS system was successfully installed and operated (transferred) on the LM at Nesson Valley in early September 2005. There were a few adjustments made in the software to accommodate differences between the Prosser and the Nesson Valley LM systems. The system was tested in a single event using the quadratic water application pattern when pulsing a bank of nozzles along the LM pathway.

The RIMCS showed comparable accuracies to those obtained with the installation in Prosser as the intended water application depth pattern was achieved with reasonable errors, $-8.8 \pm 8.1\%$ and $-0.14 \pm 6.7\%$ for spans 2 and 3 respectively, (Fig. 9; Table 6). The relative larger errors for span 2, displayed in Table 6, were most probably due to the effect of the LM cart advance/stop pattern, which affects the spans closer to the cart Chávez and Pierce (2006).

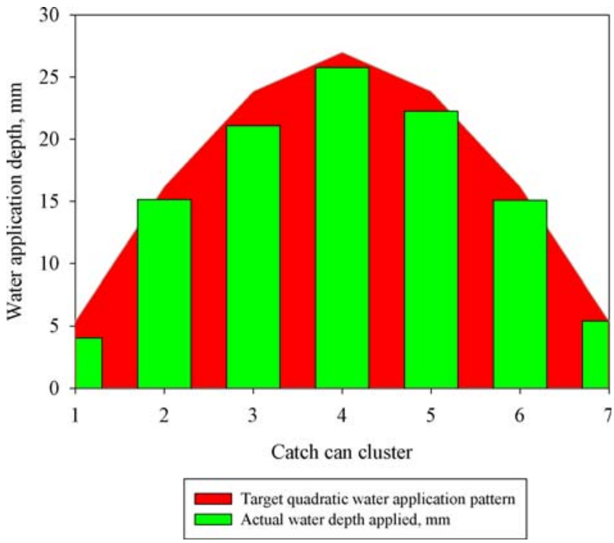

Fig. 9 North Dakota quadratic application catch can test, September '05

Table 6 North Dakota catch can test results

	MBE (%)	RMSE (%)	b_0	b_1	R^2
Span 02	−8.80	8.1	0.482	1.053	0.99
Span 03	−0.14	6.7	0.539	0.968	0.97

The Nesson Valley installation and test demonstrated the transferability of the RIMCS to other irrigation system configurations and field orientations.

The water application errors were of the same magnitude as the potential errors from external sources (other than the control system) such as sprinkle water evaporation-drift (Kincaid et al. (1996); Ortega et al. (2000); Kolh et al. (1987)), catch can evaporation, catch can shape effect (Hendawi et al. 2005), graduated cylinder reading error, and the typical linear move water application coefficient of uniformity which was 88.0–96.0%.

Conclusions

A remote irrigation monitoring and control system (RIMCS) installed on two different linear move irrigation systems was evaluated. In general, all segments of the system worked well and the system proved to be highly flexible and capable of integrating a series of in-field and on-irrigation system wireless monitoring spread spectrum radios/sensors networks. All SS100 remote radios/sensors on board of the linear move manifolds and in the field worked well sending continuous wireless data to the server database.

A GIS comparison of the submitted and executed "ON-TIME" maps showed that the control system performed well, pulsing individual nozzle/solenoid valves (On/Off) according to prescriptions maps. However, some deviation from the prescribed irrigation pattern was evident at the variable irrigation pattern block boundaries where the average nozzle/solenoid valve positioning error, on average, was 2.5 ± 1 m. This error most probably was due to the inherent DGPS accuracy. Nevertheless, the error is considered small when compared to typical sizes of irrigation zones and when considering that at the borders, between irrigation zones, there will be water application depth or rate blending.

The RIMCS as installed in Prosser showed an overall variable irrigation application error of −4.5 ± 5.5% (MBE ± RMSE) in June and −2.0 ± 3.5% in August; when considering the cumulative water depth applied. For these tests, individual nozzles were pulsed across the span length, while the errors were −7.3 ± 9.9% when pulsing banks of nozzles along the travel path of the linear move. For the Nesson Valley installation, the RIMCS system worked as designed with errors of −8.8 ± 8.1% and −0.14 ± 6.7% for spans 2 and 3 respectively; when pulsing banks of nozzles to apply a quadratic irrigation pattern. The RIMCS was able to switch irrigation patterns near specified locations with an error of 4–5 m as verified by tests at the irrigation blocks boundaries. It seems that the positioning error was caused by the GPS accuracy and the linear move advance/stop movement pattern. Furthermore, the RIMCS operated single as well as banks of nozzles and worked well pulsing nozzles across the spans and along the linear move travel direction. The RIMCS was successfully transferred to a different variable irrigation system and field orientation in the Nesson Valley of North Dakota. Some limitations include the GPS accuracy, terrain slope, and the linear move cart/tower “stop/advance” movement pattern which contributed to larger application errors for individual irrigation events.

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